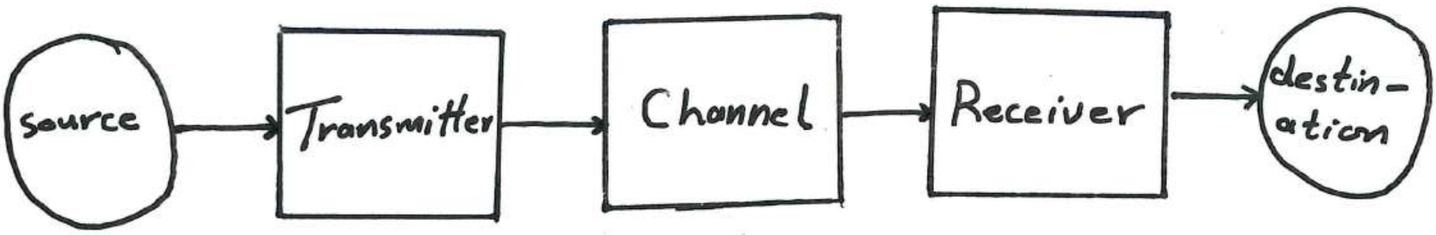
General Introduction

Communication: is the process of establishing a link between two points for information exchange.

Communication System: is a system conveys information from its source to a certain destination.



- The source generates a message, e.g: voice, image, data..
- The transmitter modifies the message for efficient transmission.
- The channel is a medium (such as wire, coaxial cable, optical fiber, or radio link) through which the transmitter output is sent.
- The receiver reprocess the signal received from the channel by undoing the transmitter's modifications.
- The destination is the unit to which the message is communicated.

The essential parts of any communication system are:

1. Transmitter.
2. Channel.
3. Receiver.

1. Classification of Communication Systems:

Communication systems can be classified according to:

a) Direction of transmission.

b) Nature of transmission.

c) Media used for transmission.

d) Transmission technique.

[a] Direction of Transmission:

Communication systems are classified to:

1. Simplex Systems:
   The information is communicated in only one direction. e.g: radio, TV broadcasting.
2. Half Duplex Systems:
   Systems allow communication in both direction, but not simultaneously, eg: walkie-talkie.
3. Full Duplex Systems:
   These systems allow communcation in both directions simultaneously, e.g: telephone, mobile systems, ...

[b] Nature of Transmission:

1. Analog Systems:
   The signals in these systems are analog signals which varies continuously with time.

2. Digital Systems:

In this system, the signals to be transmitted are digitals which has distinct levels, eg: binary signal has two distinct levels High(1) and Low(0).

C Media Used for Transmission:

1. Wire Systems:

The communication takes place through wire pairs, coaxial cables, optical fibers, and so on.

2. Wireless Systems:

In these systems, no wires or any such media are used for communication. These systems are called radio communications systems.

D Transmission Techniques:

1. Baseband Technique:

The data is transmitted over the channel directly. This kind of transmission is suitable for short distances.

2. Transmission Using Modulation:

The data is transmitted after it is modulated by a high frequency carrier. They are suitable for long distance transmission, and they are also called Passband data transmission.

2. Classification of Signals:

The signal is a <u>function</u> that represents a physical quantity.

The signal is represented by $x(t)$, which is a function of time (t). Several classification of the signals are presented such as:

A. Continuous-Time and Discrete-Time signals.

B. Analog and Digital signals.

C. Periodic and Aperiodic signals.

D. Deterministic and Random signals.

E. Energy and Power Signals.

A Continuous-Time and Discrete-Time Signals:

* Continuous-time signal is a signal that is specified for every value of time (t), and it is represented by $x(t)$. eg: sinusoidal signal, telephone output, ...
* Discrete-time signal is a signal that is specified only at discrete values of (t), e.g: montly sales of a corporation, stock market daily average, ...
  It is represented by $x[n]$, where n is integer.

B Analog and Digital Signals:

* If a continuous-time signal $x(t)$ can take values within a continuous range, then it is called an <u>analog signal</u>, eg: $x(t) = 5\sin(\omega t)$.

* If a discrete time signal $x[n]$ can take only a finite number of distinct values, then it is called a digital signal, e.g: binary signal.

C Periodic and Aperiodic Signals:

* The periodic signal repeats its values every certain period of time (T_o):

$$\boxed{x(t) = x(t + nT_o)} \quad \text{where } n \text{ is an integer}$$

T_o is called the signal period, so the signal frequency (f_o) is given by:

$$\boxed{f_o = \frac{1}{T_o}} \quad Hz$$

* Any signal does not satisfy the above condition, it is said to be nonperiodic or aperiodic signal.

D Deterministic and Random Signals:

* Deterministic signals have predictable values for for any given time, e.g: $x(t) = 10 \cos(10^6 t)$.
* Random signals take random values that can not be predicted at any given time. All message signals are random, and most of the noise signals are also random.

E Energy and Power Signals:

* The normalized energy content (E) of a signal $x(t)$ is defined as:

$$\boxed{E = \int_{-\infty}^{\infty} |x(t)|^2 \, dt}$$

* The <u>normalized average power</u> (P) of a signal $x(t)$ is defined as:

$$\boxed{P = \lim_{T\to\infty} \frac{1}{T}\int_{-T/2}^{T/2} |x(t)|^2\, dt}$$

- For <u>energy</u> signals :

$$0 < E < \infty \quad \underline{\text{and}} \quad P = 0$$

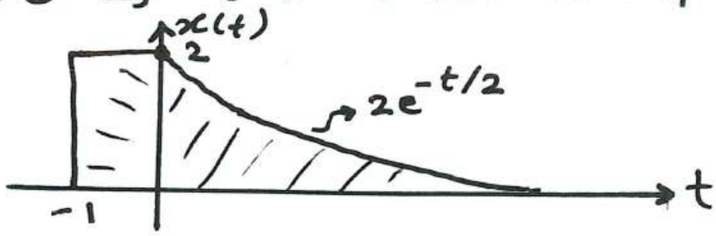
- For power signals:

$$E = \infty \quad \underline{\text{and}} \quad 0 < P < \infty$$

* Note that, both conditions should be satisfied for each signal type.

<u>Notes :</u>

1. The energy signal must be finite with time, such that $x(t) \to 0$ as $t \to \infty$, for example:

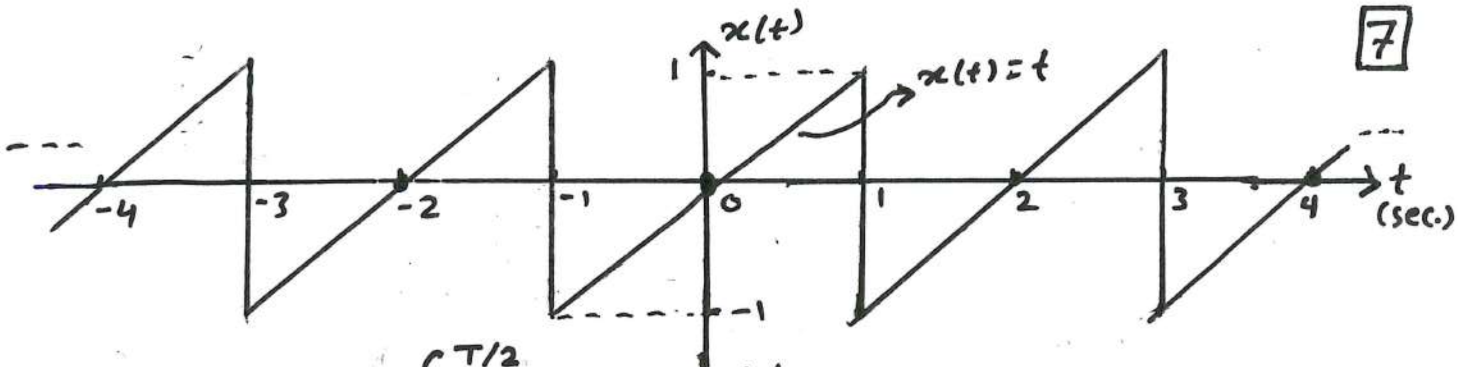


$$x(t) = \begin{cases} 2 & -1 < t \leq 0 \\ 2e^{-t/2} & 0 < t < \infty \end{cases}$$

$$E = \int_{-\infty}^{\infty} |x(t)|^2 dt = \int_{-1}^{0} 2^2\, dt + \int_{0}^{\infty} (2e^{-t/2})^2\, dt$$

$$E = \int_{-1}^{0} 4\, dt + \int_{0}^{\infty} 4e^{-t}\, dt = 4 + 4 = \boxed{8}\ \text{J}$$

2. The power signal must nessarily have an infinite duration such that $x(t)$ does not approach to zero as $t \to \infty$. Periodic signals are an example of power signals, but not all power signals are periodic, for example:



$$P = \frac{1}{T}\int_{-T/2}^{T/2} |x(t)|^2 dt \quad , \text{where } T = 2 \text{ sec.}$$

$$P = \frac{1}{2}\int_{-1}^{1} t^2 dt \Rightarrow \boxed{P = \frac{1}{3} \text{ Watt}}$$

Example: Determine whether the following signals are energy signals or power signals.

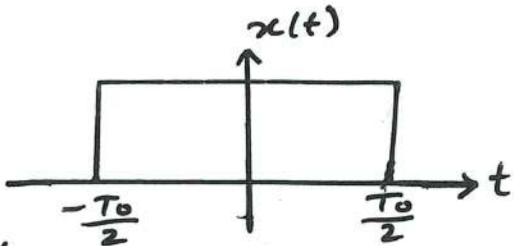
a) $x(t) = \begin{cases} 1 & -\frac{T_0}{2} \leq t \leq \frac{T_0}{2} \\ 0 & \text{otherwise} \end{cases}$

b) $x(t) = \cos \omega_0 t$

c) $x(t) = \begin{cases} \cos \omega_0 t & -\frac{T_0}{2} \leq t \leq \frac{T_0}{2} \\ 0 & \text{otherwise} \end{cases}$

Sol.

a) $x(t) = \begin{cases} 1 & -\frac{T_0}{2} \leq t \leq \frac{T_0}{2} \\ 0 & \text{otherwise} \end{cases}$



This signal has a finite duration, so it can be an energy signal if $0 < E < \infty$. Therefore, let's check its energy:

$$E = \int_{-\infty}^{\infty} |x(t)|^2 dt = \int_{-T_0/2}^{T_0/2} (1)^2 dt$$

$$E = t \Big|_{-T_0/2}^{T_0/2} \Rightarrow \boxed{E = T_0}$$

$\therefore$ This signal is an energy signal.

b) $x(t) = \cos \omega_0 t$

This signal is periodic signal with <u>infinite duration</u>, so it can be a power signal if $0 < P < \infty$.

$$P = \frac{1}{T}\int_{-T/2}^{T/2} |x(t)|^2\, dt \qquad , \text{where } T = T_0$$

$$P = \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} \cos^2 \omega_0 t\, dt$$

$$P = \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} \left(\frac{1}{2} + \frac{1}{2}\cos(2\omega_0 t)\right) dt$$

$$P = \frac{1}{T_0}\left[\int_{T_0/2}^{T_0/2} \frac{1}{2}\, dt + \int_{-\frac{T_0}{2}}^{T_0/2} \underbrace{\frac{1}{2}\cos(2\omega_0 t)\, dt}\right]$$

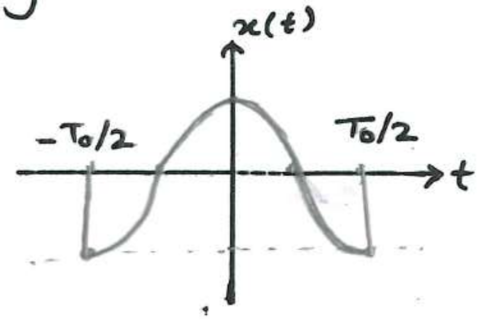
→ integration of sinusoidal over full period of time = zero

$$\therefore \quad P = \frac{1}{T_0}\left[\frac{1}{2}t\Big|_{-T_0/2}^{T_0/2} + \text{zero}\right]$$

$$\therefore \quad \boxed{P = \frac{1}{2}} \ \text{W}$$

$\therefore$ This signal is power signal.

c) $x(t) = \begin{cases} \cos \omega_0 t & -\frac{T_0}{2} \le t \le \frac{T_0}{2} \\ 0 & \text{elsewhere} \end{cases}$



This signal has a <u>finite duration</u>, so it can be energy signal.

$$E = \int_{-\infty}^{\infty} |x(t)|^2\, dt$$

$$E = \int_{-T_0/2}^{T_0/2} \cos^2 \omega_0 t\, dt$$

$$E = \int_{-T_0/2}^{T_0/2} \left(\frac{1}{2} + \frac{1}{2}\cos(2\omega_0 t)\right) dt$$

$$E = \frac{1}{2}\int_{-T_0/2}^{T_0/2} dt + \frac{1}{2}\int_{-T_0/2}^{T_0/2} \cos(2\omega_0 t)\, dt$$

$$\boxed{E = \frac{T_0}{2}} \ \text{J}$$

$\therefore$ The signal is energy signal.

Signals and Spectra

1. Some Important Signals:

Some signals are frequently used in communication systems and signal processing analysis such as:

a. Unit Step Function $u(t)$

b. Unit Impulse Function $\delta(t)$.

c. Signum Function $sgn(t)$.

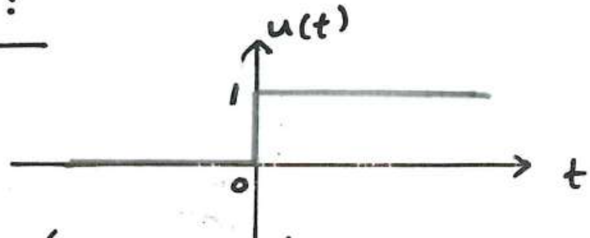
d. Sinc Finction $sinc(t)$.

e. Rectangular Pulse $\Pi(t/\tau)$.

f. Triangular Pulse $\Lambda(t/\tau)$.

a Unit Step Function $u(t)$:

$$u(t) = \begin{cases} 1 & t \geq 0 \\ 0 & t < 0 \end{cases}$$



Note that this function is discontinuous at $t=0$, where

$u(0^-) = 0$ and $u(0^+) = 1$

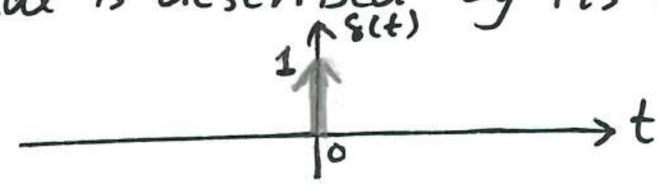
b Unit Impulse Function $\delta(t)$:

Also known as "Delta Function" or "Dirac Function"

$$\delta(t) = \begin{cases} \infty & t = 0 \\ 0 & \text{otherwise} \end{cases}$$

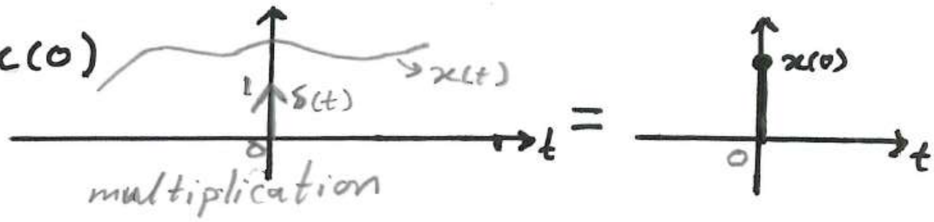
but $\int_{-\infty}^{\infty} \delta(t)\, dt = 1$

Since its value is ∞, the mathematical representation of this signal is described by its strength (integration).

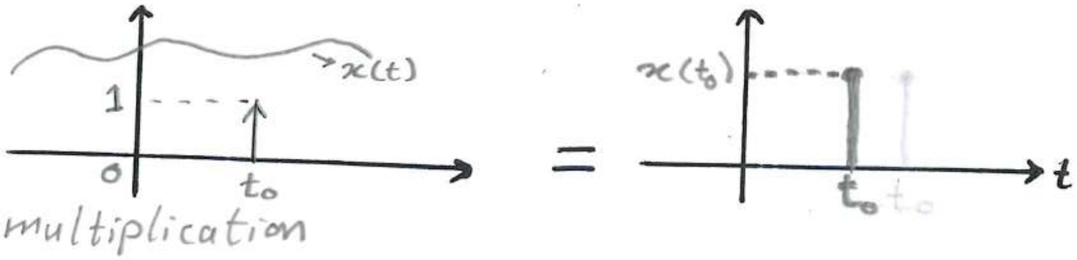


Properties of $\delta(t)$:

* $\int_{-\infty}^{\infty} x(t)\,\delta(t)\,dt = x(0)$



* $\int_{-\infty}^{\infty} x(t)\,\delta(t-t_0)\,dt = x(t_0)$



OR it can be re-written as:

$$x(t)\,\delta(t-t_0) = x(t_0)\,\delta(t-t_0)$$

$$x(t)\,\delta(t) = x(0)\,\delta(t)$$

* $\delta(at) = \frac{1}{|a|}\,\delta(t)$ for $a \neq 0$

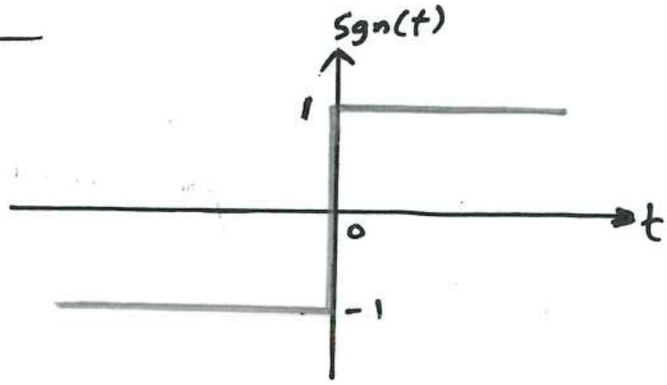
* $\delta(-t) = \delta(t)$ because it is an even function

* $\boxed{\delta(t) = \frac{d}{dt}\{u(t)\}}$, $\boxed{u(t) = \int_{-\infty}^{t} \delta(t)\,dt}$

C The Signum Function $sgn(t)$:

It is defined by:

$$sgn(t) = \begin{cases} -1 & t<0 \\ +1 & t>0 \end{cases}$$



$$\boxed{sgn(t) = 2u(t) - 1}$$

OR $u(t) = \frac{1}{2}[sgn(t) + 1]$